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SNS 104050204-TR0001 - R00

SNS Actuator Position Accuracy Tests

Introduction
The accuracy of a beam profile measurement using a wire scanner actuator depends in part on the positioning accuracy of the actuator. The greater the error in the actuator position, the greater the error in the beam profile. To quantify the actuator position error we have measured the positioning accuracy of prototype 3-inch and 6-inch stroke actuators from Huntington Mechanical Laboratories. In this tech note we will describe our measurements and discuss their impact on SNS beam profile measurements.

Method
We made our measurements on 8/Nov/02 in the LANSCE-2 shop in the MPF-3 basement under the LANSCE control room. Sonny Cordova (LANSCE-2) set up the optical alignment equipment and made the position measurements. We tested two actuators – a 3-inch stroke actuator, serial no. 103007, model no. L-2250-3-T-LWS, and a 6-inch stroke actuator, serial no. 103013, model no. L-2250-6-T-LWS. Both units were cycled a little more than 2000 times prior to our measurements. With one actuator at a time mounted vertically on a beam box, a lead block weighing about 5 kg was suspended from the actuator to simulate the vacuum load. We started each measurement series with the actuator at the out limit, then issued to the stepper motor a fixed number of pulses to move from one position to the next. At each position we measured the x and y (horizontal and vertical) positions, and read out the LVDT. The x and y position measurements are relative and not absolute. The estimated measurement error in the vertical direction is ±100 microns, and the estimated measurement error in the horizontal direction is ±50 microns.

For motion control we used the prototype SNS wire scanner signal processor and PC chassis with the National Instruments PCI-7344 controller and MID-7604 PCI power drive. Wynn Christensen wrote LabVIEW software to interface with the controller and read back the limit switches and LVDT through the signal processor. The LabVIEW program used was CycleTest&Accuracy.vi rev. 29. Before beginning the position accuracy measurements we explored various acceleration and velocity settings. We found that the actuators ran smoothly and reliably with the velocity set to 20 mm/s and the acceleration set to 40 mm/s^2. We used these settings for all the positioning accuracy measurements.

Results – 3 inch actuator

We tested the 3-inch actuator by moving it in 4 mm steps, starting from the out limit. The 4 mm step size was an input parameter to the LabVIEW program. It is not necessarily exactly 4 mm, since for the purpose of these measurements all we needed was a fixed step size. A plot of the vertical position vs. the step number is shown in Fig. 1. In this figure the data have been fit with a straight line. The residuals of the fit are shown in Fig. 2. The rms of the residuals gives the rms error in the y position, and the result for this particular set of measurements is 0.0057 inches, or 0.14 mm.

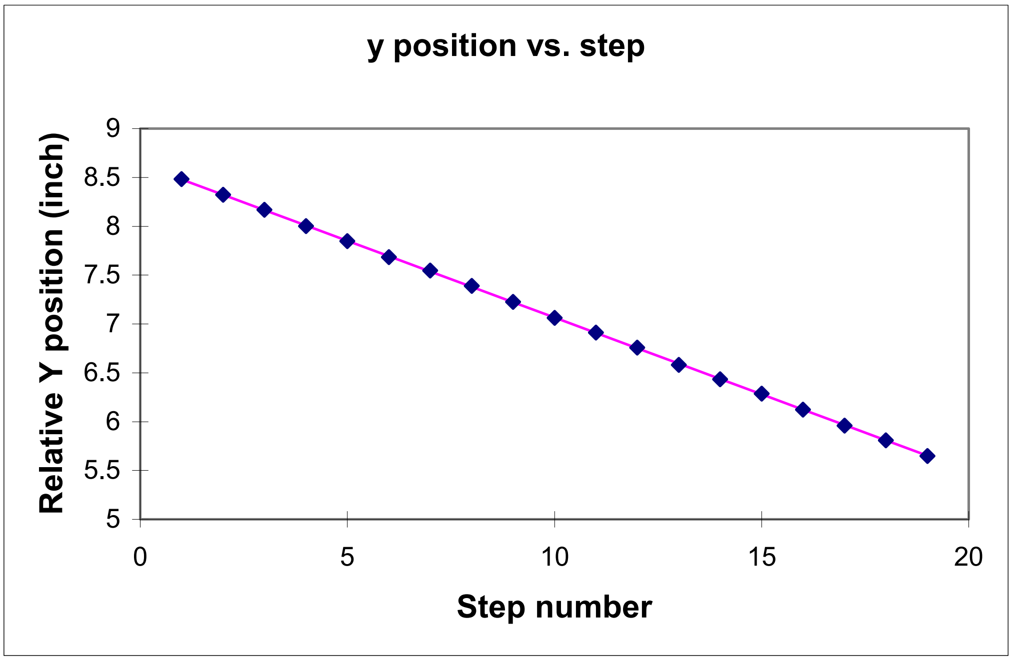

Figure 1. Relative y position vs. step number for the 3-inch actuator. The data have been fit with a straight line.

Ideally, for an actuator mounted vertically, the x, or horizontal, position will not change as the actuator is moved. However, a slight x position variation was measured for this actuator. A plot of the measured variation is shown in Fig. 3. The rms deviation from the average is 0.0026 in (0.066 mm).

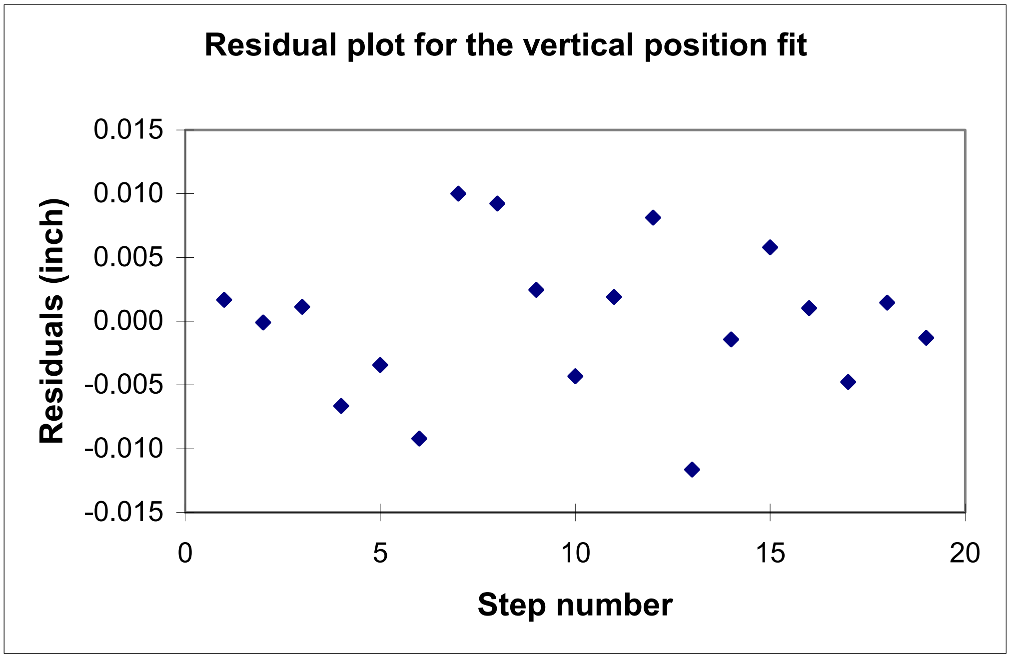

Figure 2. Plot of residuals for the straight line fit to the vertical position data for the 3-inch actuator.

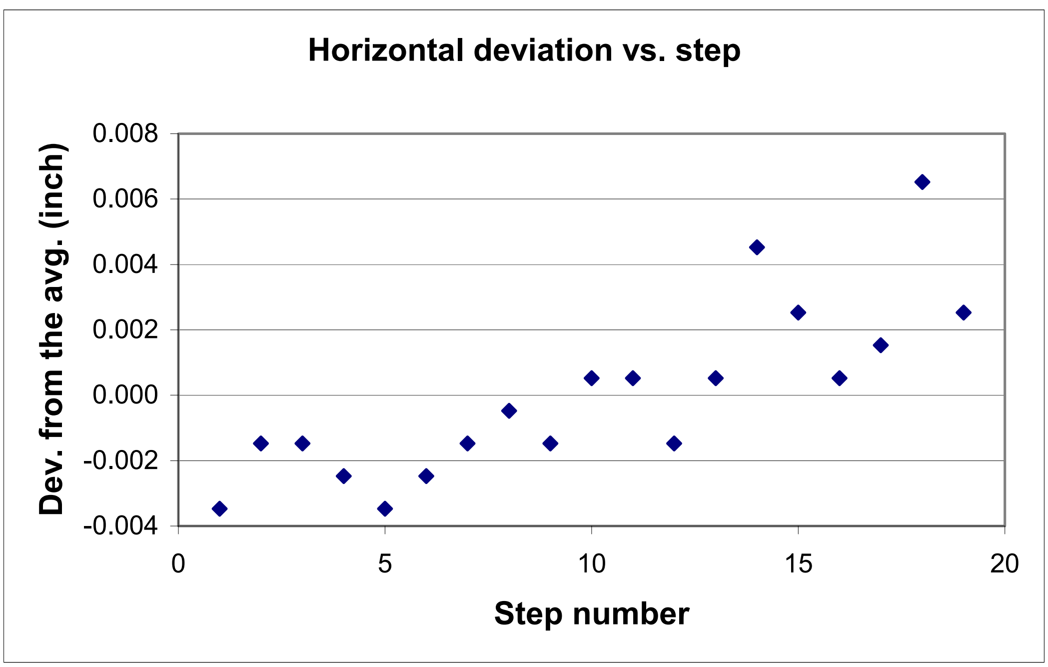

Figure 3. Plot of horizontal deviation from the average.

LVDT readback – 3 inch actuator

While making the above measurements we also recorded the LVDT readback at each step. Ideally a plot of the LVDT readback will be a straight line. A plot of our measured data is shown in Fig. 4. The fitted line has a slope of 506 counts per inch, and the deviations of the data from the line are as high as 54 counts, which corresponds to about 0.1 inches. Clearly there is something wrong with this LVDT. (The problem was traced to a 6-inch LVDT core in the 4-inch LVDT, and no core extension rod.)

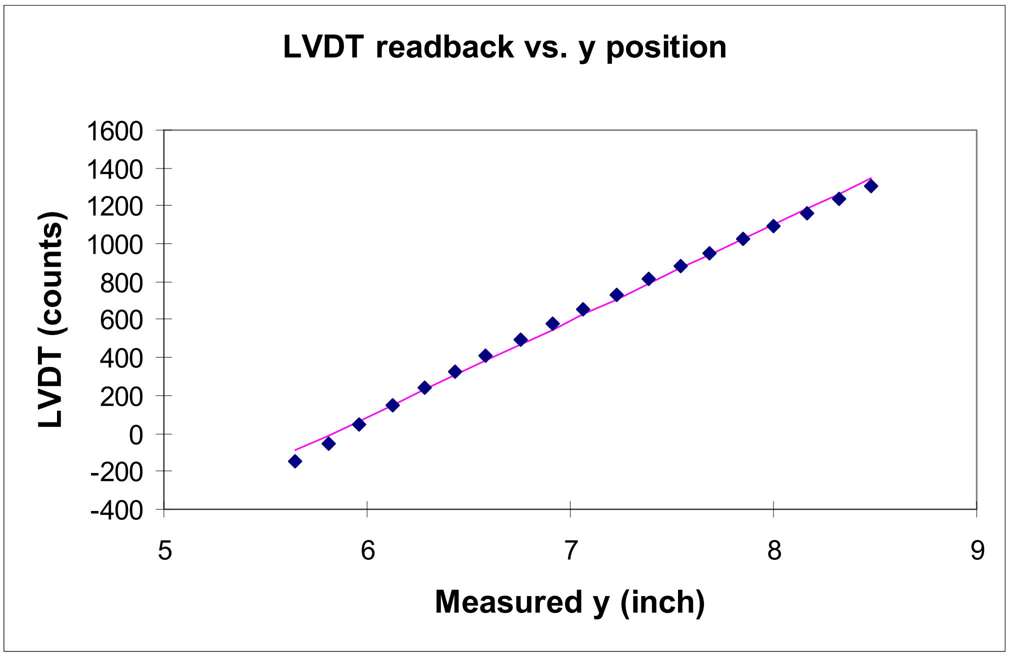

Figure 4. Plot of LVDT readback vs. measured y position for the 3-inch actuator.

Results – 6 inch actuator

We tested the 6-inch actuator by moving it in 6 mm steps. Again, the 6 mm step size was an input to the LabVIEW program and is not necessarily exactly 6 mm. A plot of the vertical position vs. the step number is shown in Fig. 5. In this figure the data have been fit with a straight line. The range of the data is limited to about 4 inches because the alignment target we were using on the end of the actuator disappeared from view below the aperture of the beam box used to mount this actuator.

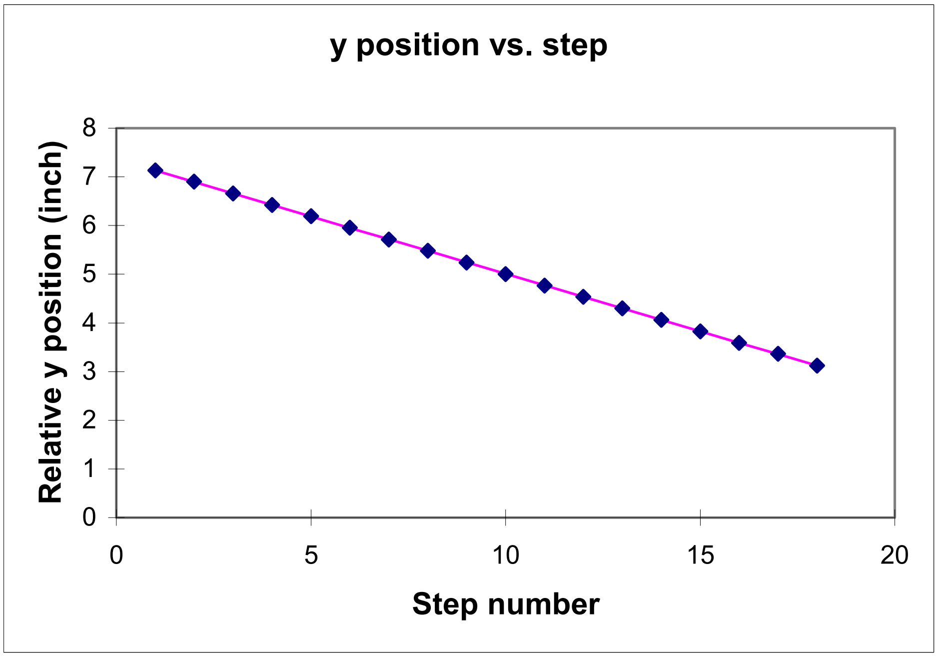

Figure 5. Relative y position vs. step number for the 6-inch actuator. The data have been fit with a straight line.

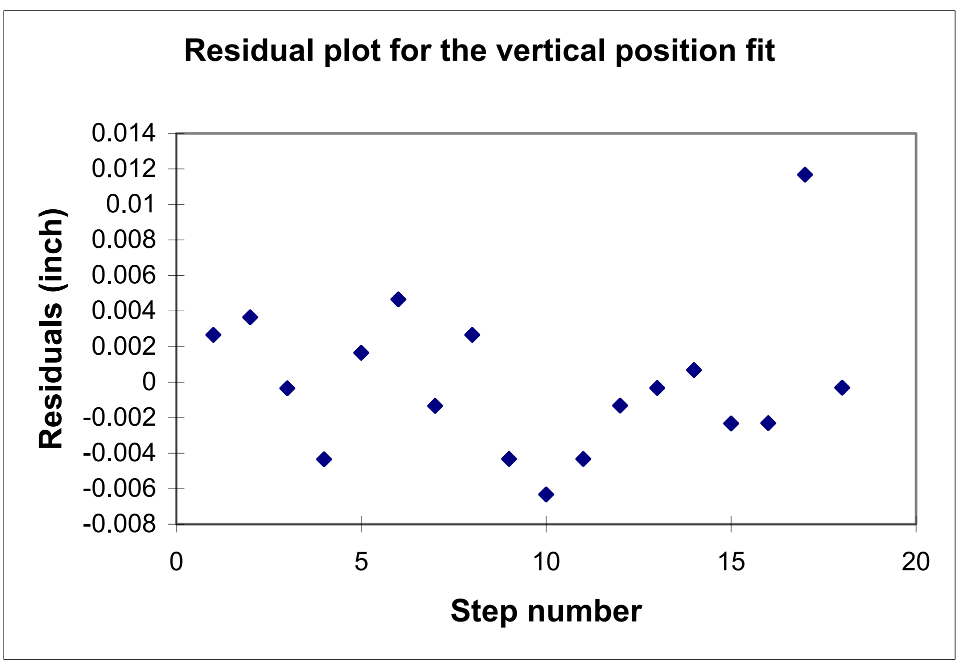

Figure 6. Plot of residuals for the straight-line fit to the vertical position data for the 6-inch actuator.

The residuals of the fit are shown in Fig. 6. The rms of the residuals gives the rms error in the y position, and the result for this particular set of measurements is 0.0041 inches, or 0.10 mm. As for the case of the 3-inch actuator, we show the horizontal deviation from the average in Fig. 7. The rms horizontal deviation from the average is 0.0023 inch, or 0.058 mm.

LVDT readback – 6 inch actuator

As in the case of the 3-inch actuator, while making the above measurements we also recorded the LVDT readback at each step. As for the case of the 3-inch actuator, this actuator was fabricated without a core extension rod, thus causing the core to be offset several inches from its optimum position in the LVDT transducer body. A plot of our measured data is shown in Fig. 8. Clearly the data do not resemble anything close to a straight line. This LVDT and the LVDT on the 3-inch actuator must be re-measured once the proper core connecting rods are installed.

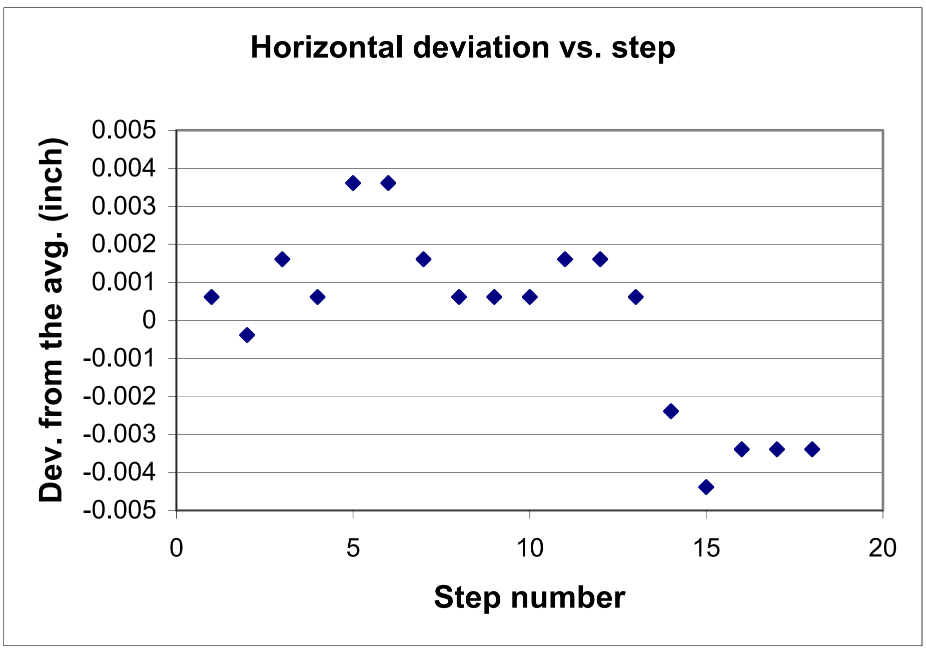

Figure 7. Plot of horizontal deviation from the average for the 6-inch actuator.

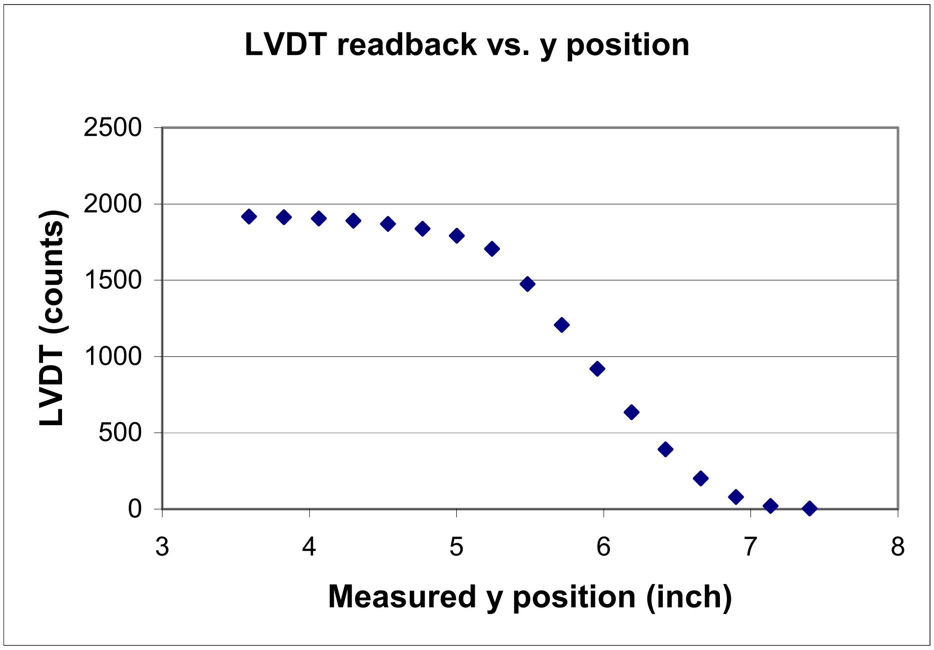

Figure 8. Plot of LVDT readback vs. measured actuator position for the 6-inch actuator.

LVDT readback – 6 inch actuator, re-measured

On 29/Jan/03 the LVDT readback on the 6-inch prototype actuator was re-measured, this time with the correct LVDT core extension rod from Macro Sensors. The rod is made of 303 stainless steel and is continuously threaded with a 6-40 thread. The actuator was set up in MPF-365, with a heavy metal plate suspended from the actuator to simulate the vacuum load. We used chopper driver serial number 11, and the same velocity and acceleration parameters as for the above measurements. We took LVDT and stepper motor pulse readings every 10 mm. The actuator was moved from its out limit toward its in limit. A straight line fit to the data is shown in Fig. 9.

The maximum deviation from the line is 11 counts, which corresponds to 0.43 mm. The specified maximum non-linearity is 0.25% of the full-scale range (6 inches), or 0.38 mm. The difference can be explained by the non-linearity of the actuator used to make this measurement (up to about 0.006 inches, or 0.25 mm, as shown in Fig. 2). Our conclusion is that the measured LVDT non-linearity is consistent with the manufacturers specification of 0.38 mm.

Measurement of pulses per inch

The pulses per rotation for the stepper motor is 200, there are 125 micropulses per pulse, and the lead screw has a pitch of 8 rotations per inch. All this boils down to 7874.02 pulses/mm. For one series of measurements on the 6-inch actuator we also recorded the pulses issued to the motor (as displayed on the LabVIEW screen). The actuator was advanced eight times in 1 mm steps. Each time the total number of pulses issued to the motor increased by 7874, as expected. After 8 movements the number of pulses increased by 62,992, and the actuator's measured position had changed by 8.026 mm. For these measurements the theodolite itself was not moved up or down – just the cross-hairs dial was moved. The accuracy of the 8.026 mm is therefore about ±0.05 mm, or 0.062%. The measured pulses per mm is then 62,992 / 8.026 = 7848 pulses/mm ± 0.062%. This error bar easily encompasses the calculated value of 7874 pulses/mm. The 7874 number is therefore experimentally confirmed within experimental errors.

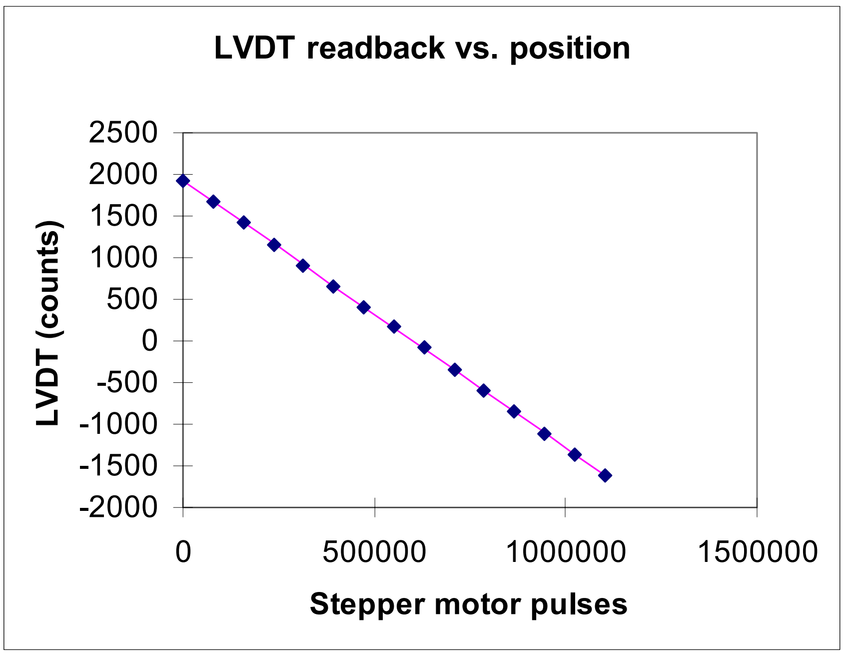

Figure 9. Plot of LVDT readback vs. measured actuator position for the 6-inch actuator, re-measured on 29/Jan/03.

Analysis

For the SNS wire scanner application these actuators will be mounted at a 45-degree angle and will hold forks with three wires in the horizontal, vertical, and diagonal orientations. The diagonal wire will be essentially unaffected by any "horizontal" deviations of the actuator, since these deviations will cause the wire to just move along its length. However, the horizontal and vertical wires will move at a 45-degree angle relative to the direction defined by their length, thus adding to the "vertical" actuator position error. The worst-case total rms error ε is then the rms "vertical" error added in quadrature to the rms "horizontal" error multiplied by $1/\sqrt{2}$. For the case of the 3-inch actuator, the total position error is:

$$\varepsilon = \sqrt{(0.14\,\text{mm})^2 + ((0.066\,\text{mm})/\sqrt{2})^2} = 0.15\,\text{mm} = 0.0058\,\text{in}.$$

For the case of the 6-inch actuator, the total position error is:

$$\varepsilon = \sqrt{(0.10\,\text{mm})^2 + ((0.058\,\text{mm})/\sqrt{2})^2} = 0.11\,\text{mm} = 0.0043\,\text{in}.$$

Conclusions

The total position error for the 3-inch actuator, i.e the sum of the "horizontal" and "vertical" error, is 0.15 mm. This actuator will be used in the CCL, where the minimum beam size is expected to be 0.5 mm rms. As described in technical note[1] SNS-104050200-TR0015-R00 (also numbered SNS-NOTE-DIAG-75), assuming an absolute signal error equal to 2% of the peak signal, and a relative signal error of 1% of the signal, a position error of 0.15 mm leads to an error in the measurement of the rms profile size of about 7%. The position error contributes very little to this profile error – it is dominated by the signal errors.

The total position error for the 6-inch actuator is 0.11 mm. This actuator will be used in the DTL, where the minimum beam size is expected to be 0.7 mm rms. Again, as described in technical note SNS-104050200-TR0015-R00, assuming an absolute signal error equal to 2% of the peak signal, and a relative signal error of 1% of the signal, a position error of 0.11 mm leads to an error in the measurement of the rms profile size of about 7%. As in the case of the 3-inch actuator, the position error contributes very little to the profile error.

The position errors in these actuators therefore have only a small contribution to the error in the rms beam size measurement, even after having been cycled over 2000 times. Both actuators have sufficient positioning accuracy to meet the requirement to measure the SNS linac rms beam sizes with an accuracy of ±10%.

The LVDT non-linearity was measured for the 6-inch LVDT on the 6-inch actuator, and was found to be consistent with the manufacturer's specification of ±0.38 mm.

Acknowledgements

Thanks to Steve Armijo, Wynn Christensen, Sonny Cordova, and Ross Meyer Sr., for all their help making these measurements.

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[1] M. Plum, "Errors in the beam width and beam position measured with the SNS linac wire scanner system," SNS-104050200-TR0015-R00 and SNS-NOTE-DIAG-75, 19/Jun/02.